COMPARISON OF EVAPORATION FROM WEATHER BUREAU CLASS A AND BUREAU OF PLANT INDUSTRY (BPI) SUNKEN PANS, FORT ASSINNIBOINE, MONTANA

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ABSTRACT

Comparative evaporation measurements for both BPI sunken and WB Class A pans at Fort Assiniboine, Mont., for an 8-year period, are reported and are subjected to several elementary analyses which indicate that pan-to-pan ratios determined in one area are not necessarily applicable to any other. The latter point is shown by a comparison of ratios from several widely separated points in the nation. Comparative pan temperatures (maximum, minimum, and mean) are also tabulated and discussed.

1. INTRODUCTION

The need for more useful water loss information has been reflected during the last 20 years in a fairly large number of studies devoted to evaporation and transpiration. In an effort to determine the relationship between Weather Bureau (WB) Class A and Bureau of Plant Industry (BPI) sunken evaporation pans at one of the more northerly latitudes of the United States, evaporation measurements were made from both types of pans, exposed adjacent to each other in the instrument enclosure of the climatological station at North Montana Branch Experiment Station, Fort Assinniboine, Mont. (near Havre).

As both types of pans have been used extensively across the nation, the physical characteristics of each require only brief description. Both are illustrated very well by Kohler [1] in his photographs of pan installations at Lake Hefner. Briefly, the WB Class A pan is 48 inches in diameter and 10 inches deep. This pan is exposed on spaced 2 in. x 4 in. lumber so that its bottom is a little above the ground and air can circulate beneath the pan. The water is maintained at a depth of about 7 or 8 inches. On the other hand, the BPI pan is 72 inches in diameter and is 24 inches deep. It is set in the ground to a depth of 20 inches, leaving about 4 inches of the pan rim standing above the soil surface. The BPI water level is maintained ideally at near the ground level. Micrometers exposed in stilling wells were used for measuring daily evaporation amounts in both pans. Both were exposed in a fenced enclosure, with a free flow of air over both water surfaces. When the BPI pan developed a leak early in the 1957 season, it was abandoned, and the Class A pan has since been used for evaporation measurements for the Experiment Station.

Figure 1 is a photograph of the Fort Assinniboine instrument enclosure as it was throughout the period of comparisons. The installation is standard except that in an attempt to have one anemometer serve both pans, this instrument was not mounted on the Class A pan base, was some 15 inches higher than standard above the pan rim, and was located several feet from both pans. While these factors would tend to produce slightly higher wind movements than a standard installation would have, the fact

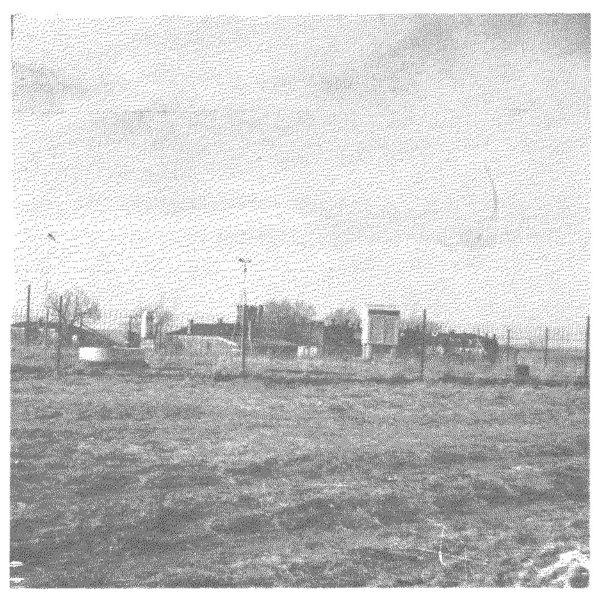

FIGURE 1.—Fort Assinniboine, Mont. Instrument exposure (looking north). BPI pan is in center foreground of enclosure, Class A pan on left, and ground level anemometer behind the Class A pan.

remains that, in cases of this kind where wind movement is fairly large in any case, effects of this factor on total evaporation are small.

Considering the large number of evaporation installations of either Class A or BPI sunken types, it is quickly recognized that available evaporation data in terms of either pan can be increased considerably across the nation if simple conversion factors for computing reasonable values of one pan from observations of the other can be determined either experimentally or theoretically. In fact, if the required theoretical parameters can be more easily measured or estimated than actual evaporation, for some locations it may be possible to achieve reasonable and usable estimates without the need for several years of actual measurements. The purposes of this paper are to report actual comparisons at Fort Assinniboine over an 8-year period; to compute theoretical evaporation for the part of the period for which the necessary parameters are available; to compare these theoretical, or analytical, results with actual measurements for the same period; to summarize water temperatures for both pans for about five years; and to discuss the results and some of their possible applications.

2. COMPARATIVE EVAPORATION MEASUREMENTS

Table 1 lists monthly evaporation totals for both pans for the 8-year period, 1949–56. Measurements are not practical for the period October–March, inclusive, because of ice problems associated with freezing temperatures, and only occasionally is a partial month of measurements obtainable in April. Comparison of actual measurements is available, therefore, only for the five months, May–September. In a few cases adjustments were made for inconsistent data, by deleting measurements

TABLE 1.—*Monthly evaporation (in.) Fort Assinniboine, Mont., latitude 48°30′ N., longitude 109°48′ W., elevation 2687 ft. M.S.L.*

Year	April	May	June	July	August	September	Seasonal
			BPI Sunken Pan (x)				
1949	6.40	6.99	8.13	9.31	9.44	6.17	
1950	3.88	5.82	5.63	7.03	6.03	4.56	
1951	----------	6.26	4.55	7.50	6.62	3.36	
1952	5.43	5.87	7.84	8.08	7.66	5.17	
1953	2.15	4.39	5.33	7.71	7.74	5.23	
1954	----------	5.97	5.30	8.39	5.59	3.99	
1955	----------	4.53	6.68	5.79	8.04	5.06	
1956	----------	4.56	7.95	7.71	7.98	4.35	
Average	----------	5.55	6.43	7.69	7.39	4.74	31.80
			Class A Pan (y)				
1949	9.53	10.00	11.24	12.95	13.01	8.25	
1950	5.95	8.94	8.73	9.86	8.47	6.28	
1951	----------	9.93	6.77	11.36	9.27	4.78	
1952	7.41	8.53	11.56	12.04	10.95	7.50	
1953	3.42	6.82	7.88	11.46	11.60	7.68	
1954	----------	8.66	7.67	12.82	8.51	5.83	
1955	----------	6.34	9.15	8.64	11.94	6.78	
1956	----------	7.43	12.13	11.46	10.71	6.75	
Average	----------	8.33	9.39	11.32	10.56	6.73	46.33
y/x		1.50	1.46	1.47	1.43	1.42	1.46
x/y		.666	.684	.679	.700	.704	.686

TABLE 2.—*Average inches of evaporation, 1949–1956, and y/x ratios*

	Montana		y/x	
	BPI (x)	Class A (y)	Montana, 8 yrs.	Kansas, 14 yrs.
May	5.55	8.33	1.50	1.48
June	6.43	9.39	1.46	1.46
July	7.69	11.32	1.47	1.45
August	7.39	10.56	1.43	1.44
September	4.74	6.73	1.42	1.45
Season	31.80	46.33	1.46	1.46

TABLE 3.—*Evaporation ratios, other experiments (after* [1])

y/x	Location	Period
1.30	Lake Kickapoo, Tex.	January 1950–December 1951.
1.20	Buchanan Dam, Tex.	January–December 1950.
1.33	Denver, Colo.	June–October 1916.
1.25	Balmorhea, Tex.	April 1941–December 1948.
1.28	Pardee Reservoir, Calif.	January 1930–December 1944.
1.29	Yuma Field Station, Calif.	January 1937–December 1939.
1.21	Fullerton, Calif.	January 1937–December 1939.
1.35	Lake Hefner, Okla.	May 1950–August 1951.

from both pans. This expedient was employed for only four dates for the entire period, and does not affect comparison because daily data from both pans were deleted when the measurement from either was questionable.

With y designating Class A evaporation and x BPI evaporation, monthly y/x ratios varied between 1.42 (September) and 1.50 (May), following closely the ratios reported in the preliminary report of the first 4 years of comparisons [2]. The seasonal y/x ratio, 1.46, agreed exactly with the results of 14 years of similar comparisons at Hays, Kans., for the slightly longer April–September 6-month period (the 5-month y/x ratio at Hays is 1.45) [3]. It seems, therefore, that the seasonal y/x relationship has been determined experimentally, at least for areas similar to Hays and Fort Assinniboine, within narrow limits (see table 2). However, in comparing these two seasonal results with results at several other locations (table 3), we find important differences, with the y/x ratio ranging from 1.20 at Buchanan Dam, Tex., to 1.35 at Lake Hefner, Okla. Noting that seasons for all eight points listed by Kohler [1] varied from one to seven months longer than the season for Fort Assinniboine, the immediate suggestion is that measuring seasonal evaporation only, and basing full year relationships thereon, cannot be justified. This suggestion is strengthened by the fact that the highest of the eight y/x ratios (outside of Fort Assinniboine and Hays), 1.33 at Denver and 1.35 at Lake Hefner, are also seasonal figures, while full-year comparisons at six of the eight yielded y/x ratios between 1.20 and 1.29.

On the possibility that May–September seasonal y/x factors would differ from those for full years or other seasons, a few were computed on the 5-month season basis for comparison. These are listed in table 4. Differences were found, but they are seen to be quite small. The figures serve to confirm that comparisons made in one section of

TABLE 4.—*Comparison of 5-month seasonal values of y/x with values for other periods*

Location	y/x	
	5-month period	Periods of other length
Fort Assinniboine, Mont	1.46	
Hays, Kans	1.45	1.46 (6 months).
Lake Hefner, Okla	1.31	1.35 (annual).
Buchanan Dam, Tex	1.19	1.20 (annual).
Lake Kickapoo, Tex	1.27	1.30 (annual).

the nation are not necessarily representative of other areas, and that geographical (and associated) differences between locations are probably at least as important as seasonal considerations.

The difficulties in making accurate evaporation measurements are well known, and appear to have had their effects on the measurements at Fort Assinniboine. Such things as heavy rains splashing out or in, high winds splashing water out of one or both pans, setting micrometer gages under high wind conditions, and pans overflowing from heavy precipitation, all make comparative daily measurements difficult and will explain some of the daily evaporation variation between pans. Most of the variation seems due, however, to consistently lower daytime temperatures of the sunken pan. The only days on which the sunken pan had a warmer maximum temperature were those with rapid cooling of the atmosphere in the area, and the sunken pan, due to a larger mass of water and heat stored both in water and surrounding earth, was slower to cool. Comparative pan water temperatures are discussed in a later section. On the basis of these comparisons it appears that the y/x ratio experimentally determined at Fort Assinniboine has application only in areas limited to similar seasonal and possibly latitudinal conditions.

3. ANALYSIS OF CLASS A AND BPI EVAPORATION

In the preceding section May–September comparisons of Fort Assinniboine evaporation from the two types of pan appear to produce a rather high y/x ratio (1.46), even though the ratio agrees almost exactly with that for Hays, Kans., for a similar season. Full year experimental comparisions at other points show an annual ratio of about 1.25. It appeared possible, in view of this large difference, that Fort Assinniboine might experience a marked lowering of the y/x ratio during winter. The reasoning which suggests this possibility is that, during the warmer season of the year when air temperatures average warmer than soil temperatures, there would be some water heat loss through the sunken pan into the ground, particularly during the warmest period of each day. (Measurement of air and soil temperatures at the 20-inch depth at Bozeman, Mont. during summer months, shows that mean air temperature during summer runs 2° to 4° F. warmer than that of soil at the 20-inch depth—the depth of the bottom of the BPI pan. The same record shows that this temperature gradient reverses during the winter, with even greater differences.) At Silver Hill, Md., the Weather Bureau has found that insulating the BPI sunken pan against heat loss increases its evaporation 6 to 8 percent. On the other hand, during the colder months at Fort Assinniboine (not comparable at all with Silver Hill), *if* evaporation were measureable, much of the time heat traveling through the BPI pan from the ground through the water (or ice) to the air (reverse of warm season) could be expected to reduce the y/x ratio appreciably by keeping the sunken pan temperature warmer relative to the air than during the summer, and increasing its comparative evaporation as a result.

An attempt was made to show heat loss to the ground through the BPI pan by computing evaporation from that pan first by using air temperature, dew point, radiation, and average daily wind movement (table 5), and comparing these results with evaporation computed from water surface temperature instead of air temperature in Dalton's [4] equation

$$E=(e_o-e_a)\ (a+bu).$$

However, the results made it apparent that the equation developed from BPI data at Lake Hefner (where [1] gives $a=0.253$ and $b=0.004$), is not applicable to Fort Assinniboine. The author cannot find the reason (or reasons) for this but further study appears desirable. It may be that heat loss through the pan from air to ground may have been most significant during the warmest part of the day, when evaporation rates were highest, and air temperatures averaged some 6° to 8° F. warmer than BPI pan water. At night, when BPI pan minimums ran 8° to 10° F. warmer than air, such factors as air temperature, differences in air and water vapor pressure, radiation, and wind were all at levels contributing to lowest diurnal evaporation rates. This is discussed in the section which follows.

In table 5 are listed data used in computations, which are based upon Penman's [6] equation,

$$E=\frac{1}{\Delta+\gamma}\ (Q_n\Delta+\gamma E_a),$$

where Δ is the slope of the saturation vapor-pressure vs. temperature curve (de_s/dT) at air temperature T_a; E_a is the evaporation given by the aerodynamic equation, assuming water temperature (T_o) equal to air temperature; Q_n is the net radiant energy expressed in the same units as E; and γ is defined by the equation

$$R=\gamma\left(\frac{T_o-T_a}{e_o-e_a}\right)$$

in which R is Bowen's [7] dimensionless ratio. The application to Fort Assinniboine data follows exactly the procedures outlined in [5]; in fact, use of the graphs of [5] yields results varying insignificantly from the computations, although actual computations were made and are

TABLE 5.—*Analytical computation of Class A and BPI pan evaporation using Havre and Fort Assinniboine meteorological data, 1955–57*

1	2	3	4	5	6	7	8	9	10	11
Month	T_a	T_d	R	U_p	Computed Class A Evap.	Computed BPI Evap.	Ratio Class A BPI	Average 1955–57 Class A Pan Obs. Evap.	Pan Coeff. from Comp. Evap.	Pan Coeff. from Obs. Evap.
January	10.4	4.0	156	155	0.90	1.26	0.71			
February	16.9	9.3	250	185	1.28	1.61	.79			
March	29.3	17.7	381	179	2.98	2.87	1.04			
April	41.9	26.3	459	169	4.77	4.29	1.11			
May	55.6	37.6	517	147	7.46	5.83	1.28	7.95		
June	63.7	44.7	625	153	10.00	7.17	1.39	9.83		
July	70.7	49.7	624	133	11.36	7.97	1.42	11.61		
August	68.0	45.3	542	128	10.02	7.16	1.40	11.00		
September	57.1	38.3	405	124	6.19	4.86	1.27	5.89		
October	45.5	30.7	253	141	3.90	3.44	1.13			
November	27.6	17.0	152	166	2.04	2.04	1.00			
December	24.2	12.7	114	176	2.01	2.02	1.00			
May-September					45.03	32.99	1.36	46.28	.665	.647
Annual					62.91	50.52	1.25		.661	

T_a Average air temperature (°F.) 1955–57 for Havre, Mont.
T_d Average dew point (°F.) 1955–57 for Havre. (Values for Aug.–Dec. 1957 and Jan. 1955 estimated from surrounding stations.)
R Average radiation, Langleys/day (interpolated from Great Falls and Glasgow observed radiation).
U_p Average pan wind, mi./day (Fort Assinniboine Class A pan).

listed in table 5. The May–September y/x ratio, based upon computed evaporation, turns out to be 1.36, compared with 1.46 for the 8-year observed ratio. This 1.46 value was remarkably stable from year to year, suggesting the possible conclusion that computed BPI pan evaporation is too large, through not allowing for sufficient heat loss through the pan during the season of highest evaporation rates. This 1.36 value might be considered an estimate of what the season y/x ratio would be if the BPI pan were insulated, representing a possible increase of about 11 to 12 percent in evaporation from the sunken pan as compared with the 8 percent increase determined experimentally at Silver Hill.

Because the Class A pan seasonal coefficient was computed to be 0.665 (factor for yielding lake evaporation from Class A totals), while the coefficient from observed data was 0.647, it may be concluded that the analytical Class A computations produce results not significantly different from observed data. This has been the experience at Lake Hefner [1] and Lake Mead [8] for longer seasons, and leads to the assumption that the analytical computations for the full year at Fort Assinniboine are reasonably good. In the 6th and 7th columns of table 5 it is interesting to note that the computed evaporation from the BPI pan is larger than similar computations for the Class A pan during midwinter, and is about the same during early spring and late autumn. It is during midsummer that the Class A pan evaporates much more than the sunken unit, and because evaporation volume is the highest at about the same time the monthly y/x ratio is largest, the winter reversal of the y/x ratio has only a small effect on the annual totals. Table 5 covers only the 3 years for which data for the computation method were available, but since the y/x observed ratio varied within a range of less than 0.10 from year to year, any changes from computing for the entire 8-year period would necessarily be small.

It should be noted from this table 5 that temperature and dewpoint data from Havre (8 miles northeast of, and 200 ft. lower elevation than Fort Assinniboine) were used. Climatologically, these two places are not identical. Fort Assinniboine has much more wind than Havre, and the Havre temperature averages 1.3° F. warmer throughout the year. This use of Havre temperatures, because of their higher average than the evaporation pan location, tends to produce higher computed evaporation values than if suitable temperature data had been available for Fort Assinniboine. Havre dewpoints would also be expected to run higher than Fort Assinniboine's, and this factor would produce lower computed evaporation values. Further, Havre has a valley bottom location, Fort Assinniboine is on a relatively flat plain; Havre rainfall runs nearly 10 percent greater than at the Fort, and the Havre instrument site has less sunshine than Fort Assinniboine. The computed values, then, must be considered rough estimates and as an example of the analysis possible if suitable data were available. Their value is in providing evaporation loss estimates for the part of the year when measurements are impractical.

The seasonal (May–September) y/x computed ratio (column 8 of table 5), when compared with observed ra ios (table 1), reveals large differences in May and June (1.28 vs. 1.50; 1.39 vs. 1.46), two months when heat loss through the sunken pan should be large because rapidly warming atmosphere and much more slowly warming earth would produce a large heat gradient toward the ground. The large difference in September (1.27 vs. 1.42), although not as large as in May, is not easily explained, and probably reflects some of the limitations of the data used in the computations.

4. WATER (BOTH PANS) AND AIR COMPARATIVE TEMPERATURES

Tables 6–8 list monthly water temperature averages for the two pans. Although a leaking BPI pan destroyed evaporation comparisons during 1957, water temperature measurements were continued for both units until the end of September, yielding a fraction more than five seasons

TABLE 6.—*Comparison of WB Class A and BPI sunken evaporation pan temperatures, Fort Assinniboine, Montana*

Year	Average Pan Maximum Temperature									
	May		June		July		August		September	
	A	BPI	A	BPI	A	BPI	A	BPI	A	BPI
1952							78.6	74.8	70.9	67.2
1953	65.7	59.8	73.1	69.2	82.2	77.6	80.0	74.9	71.0	65.8
1954	69.4	62.8	71.7	65.6	84.1	77.2	78.4	74.2	69.2	64.6
1955	61.3	58.0	*67.7	66.8	*75.2	72.6	82.1	74.9	64.3	60.8
1956	64.9	60.8	76.9	71.1	*82.0	75.7	76.8	72.3	65.9	62.9
1957	*66.6	61.9	73.4	69.2	82.1	74.3	79.2	73.6	68.9	64.6
Total	327.9	303.3	362.8	341.9	405.6	377.4	475.1	444.7	410.2	385.9
Years	5	5	5	5	5	5	6	6	6	6
Average	65.6	60.7	72.6	68.4	81.1	75.5	79.2	74.1	68.4	64.3
Diff		4.9		4.1		5.6		5.1		4.1

*These values differ from those published in *Climatological Data* for a variety of reasons. In some cases data for one pan were not used here if data for the other were unobserved for any reason, and in others small errors have been found in the publication which are being corrected.

TABLE 7.—*Average pan minimum temperature*

Year	May		June		July		August		September	
	A	BPI	A	BPI	A	BPI	A	BPI	A	BPI
1952							52.6	60.3	45.5	52.6
1953	42.5	48.7	52.0	57.4	55.5	65.1	53.3	62.1	45.6	53.5
1954	44.4	51.6	49.4	56.2	56.8	65.4	56.8	62.4	46.7	53.9
1955	43.4	49.7	*50.7	59.6	57.0	63.5	53.8	62.5	*41.7	*50.0
1956	45.2	52.3	52.7	60.0	*56.4	64.0	53.8	60.1	44.9	52.0
1957	*47.0	52.9	53.9	59.8	56.7	59.8	54.7	61.2	45.6	51.6
Totals	222.5	255.2	258.7	293.0	282.4	317.8	325.0	368.6	270.0	313.6
Years	5	5	5	5	5	5	6	6	6	6
Average	44.5	51.0	51.7	58.6	56.5	63.6	54.2	61.4	45.0	52.3
Diff		6.5		5.9		7.1		7.2		7.3

*See note to Table 6.

TABLE 8.—*Average pan water temperature*

Year	May		June		July		August		September	
	A	BPI	A	BPI	A	BPI	A	BPI	A	BPI
1952							65.6	67.6	58.2	59.9
1953	54.1	54.3	62.6	63.3	68.9	71.4	66.7	68.5	58.3	58.7
1954	56.9	57.2	60.6	60.9	70.5	71.3	67.6	68.3	58.0	59.3
1955	52.4	53.9	59.2	63.2	66.1	68.0	68.0	68.7	53.0	55.4
1956	55.1	56.6	64.8	65.6	69.2	69.9	65.3	66.2	55.4	57.5
1957	56.8	57.4	64.7	64.5	69.4	67.1	67.0	67.4	57.3	58.1
Totals	275.3	278.4	310.9	317.5	344.1	347.7	401.2	406.7	340.2	348.9
Years	5	5	5	5	5	5	6	6	6	6
Average	55.1	55.9	62.2	63.5	68.8	69.5	66.9	67.8	56.7	58.2
Diff		0.8		1.4		0.7		0.9		1.5

TABLE 9.—*Average air temperature, Fort Assinniboine*

Year	May	June	July	August	September
Maximum					
1952				84.1	76.2
1953	61.7	70.3	84.1	86.1	75.1
1954	63.9	70.5	87.1	78.6	68.7
1955	62.3	73.5	78.0	86.0	69.6
1956	65.6	78.9	83.0	80.6	71.3
1957	71.5	74.3	88.8	81.5	71.3
Average	65.0	73.5	84.2	82.8	72.0
Class A Average	65.6	72.5	81.1	79.2	68.4
BPI Average	60.7	68.4	75.5	74.1	64.3
Minimum					
1952				49.7	45.0
1953	38.1	48.1	53.6	51.9	44.2
1954	39.2	48.0	55.9	54.4	44.5
1955	40.2	47.5	54.5	50.9	39.9
1956	41.9	51.1	53.9	51.2	43.2
1957	41.8	48.7	55.4	52.7	43.5
Average	40.2	48.7	54.7	51.8	43.4
Class A Average	44.5	51.7	56.5	54.2	45.0
BPI Average	51.0	58.6	63.6	61.4	52.3
Mean					
1952				66.9	60.6
1953	49.9	59.2	68.9	69.0	59.7
1954	51.6	59.3	71.5	66.5	56.6
1955	51.3	60.5	66.3	68.5	54.8
1956	53.8	65.0	68.5	65.9	57.3
1957	56.7	61.5	72.1	67.1	57.4
Average	52.7	61.1	69.5	67.3	57.7
Class A Average	55.1	62.1	68.8	66.9	56.7
BPI Average	55.9	63.5	69.5	67.8	58.2

of water temperature comparisons. In table 9 appear average air temperatures for the same periods.

Pan average maximum temperature (table 6) was rather consistently warmer from month to month in the Class A unit, although occasionally a day with rapid cooling of the weather in general would produce a higher sunken pan water temperature. This consistent pattern (27 months) seems to imply some actual heat loss from the sunken pan to the ground, at least during the warmest (and highest evaporation) part of the day, although a large part of the difference, of course, is caused by heat radiation on the sides of the Class A pan. In table 7, however, we find that the pattern reverses; the sunken pan had consistently warmer minimums except for an occasional day when a marked warming covered the area, warming the Class A unit more rapidly than the other. Because the BPI unit was warmer only during the portion of the day with lowest overall evaporation rate (night), it may be assumed that even though the BPI pan might have a higher nighttime evaporation rate than the Class A, this effect must be more than offset by the increased Class A ratio during the heat of the day, caused by higher temperatures, possible wind differences, and other diurnal factors. A brief experiment with sunrise and sunset readings for part of a summer season seems to be suggested.

For the average overall temperature for both units, the BPI pan ran about 1.2° F. warmer than the Class A. The result must be considered along with duration of day and night during the season sampled. During June the period between sunset and sunrise lasts only 8 to 9 hours, and only for a portion of that period would the Class A water be cooler than the sunken pan water. With sunlight lasting 15 to 16 hours, and with the Class A water warming quickly after sunrise, it seems evident that the Class A water temperature would normally be the warmer of the two for at least 14 hours of each day. This could be tested by a short period of hourly observations (a month or so), or by distant recording thermographs with temperature elements immersed in the water.

Table 9 lists average air temperatures, with water temperatures for the two pans included for convenience in comparison. It is interesting to note that sunken pan temperatures compare more closely with air average means; they average much warmer than air in the average minimum category; but in the very important average maximum category, sunken pan water temperature averages much cooler. The water average maximum temperature for the Class A pan runs slightly cooler than that for air, probably due to evaporational cooling during the warmest part of the day. In another experiment of this kind it would be well to develop characteristic daily temperature curves for air and Class A and BPI water. The Fort Assinniboine results suggest that computing daily average water temperatures on the same basis (maximum plus minimum divided by 2) as for air, may be worth experimental study to determine its validity as a practice.

5. REPRESENTATIVENESS OF DATA

Table 10 lists comparative Class A evaporation figures as available in North Central Montana for the period the two pans were compared at Fort Assinniboine. A question arose as to whether Class A evaporation at that point was too high and not representative for an area. Tiber Dam, situated about 75 miles west-southwest of Fort Assinniboine, during the eight years of comparison came very close to Assinniboine totals in five years. Malta, in the bottom of the Milk River Valley, showed much less evaporation, but there the pan is in an area of much less wind movement and of somewhat higher relative humidity. Considering the Fort Assinniboine exposure along with results listed in table 10 for Tiber Dam, data from each seem to support the other, and probably indicate that while Fort Assinniboine seasonal evaporation may be high, and may be near the maximum for the area it represents, it still represents a large (perhaps as much as 3,500 sq. mi.) section of plateau country between the Milk and Marias River Valleys (Tiber Dam is on the Marias River). Reference to figure 1 will show the type of level plateau on which Fort Assinniboine is located.

TABLE 10.—*Seasonal evaporation, North Central Montana, WB Class A installations (May–September, incl.)*

Year	Fort Assinniboine	Tiber Dam	Malta	Lonesome Lake
1949	55.45	52.99	33.41	49.05
1950	42.28	39.47	26.22	----------
1951	42.11	42.06	----------	37.87
1952	50.58	47.03	27.63	37.54
1953	45.44	41.55	28.98	37.89
1954	43.49	38.17	21.95	----------
1955	42.85	36.75	27.26	----------
1956	48.48	36.79	----------	----------

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Weather Note

TWO UNIQUE EASTERN PACIFIC HURRICANES OF 1957

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1. INTRODUCTION

Most storms forming in the area southwest of Manzanillo, Mexico begin moving westward, but quickly recurve, move northward, lose their tropical identity, and fill rapidly. A few, with a higher energy level than usual, or supplemented by extratropical systems to the north, move far enough to the north to bring rain, and less often, high winds to southern California. Others curve to the northeast and move toward or into Mexico until they dissipate. At least one crossed into the Gulf of Mexico [1], moved over that body of water, and reached Florida. A very few do not recurve at all, but continue a general westward movement. In 1957 two of these latter progressed far beyond the normal paths.

This paper attempts to analyze these storms, in some measure to explain the reasons for westward movement, and to evaluate conditions which caused the early demise of the first, Kanoa, and the intensification of the second at a latitude where normally a change to extratropical type of storm would be expected.

Analysis and evaluation were severely limited by lack of data. Unlike the Caribbean-Atlantic and the western Pacific areas where many previous studies have been made on tropical storms, the area between Hawaii and Mexico is completely without upper air data and virtually without surface data. These limitations preclude accurate application of suggested forecast techniques for long periods in the lives of the storms, or may even rule out an approach completely. An example of this is clearly shown in the case of Kanoa, where the Riehl-Haggard [2] method was inapplicable because the southern part of the grid extended into an area where even normal height charts are subject to suspicion.

2. THE FIRST STORM, KANOA

Kanoa was first recognized in a bulletin issued by the San Francisco Weather Bureau office at 0700 GMT, July 15, 1957. The bulletin, based largely on a report from the ship *Gravel Park*, which reported a westerly wind of 45 knots and a pressure of 998 mb. at 2000 GMT, July 14, placed the center about 750 miles southwest of Manzanillo, Mexico. The San Francisco office continued issuing bulletins until 0900 GMT, July 18, when lack of data forced abandonment.

However, three days later, at 0300 GMT, July 21, the ship *Cape Horn*, located near 15° N., 130° W., reported 67 m.p.h. winds and very high seas with precipitous swells. On receipt of this information, the San Francisco office resumed issuance of advisories, now raising the storm into the hurricane category. The *Cape Horn* remained either in or on the periphery of the storm for the following four days, rendering invaluable aid in charting the course and intensity of the storm.

On July 22, a plane from the 57th Weather Reconnaissance Squadron, Hickam Air Force Base, Oahu, located the eye, about 40 mi. in diameter, and estimated the maximum sustained winds to be 70 kt. with gusts to 100 kt. The next day the ship *Elba* added reports that were extremely helpful in the analysis of the situation. The Air Force reconnaissance continued daily until the storm filled and winds dropped below 35 kt.

Normally, data southeast of Hawaii are conspicuous by their virtual absence. In this case, though, Kanoa travelled almost the same path as the shipping lane between Hawaii and the Canal Zone. This coincidence provided enough data to allow excellent results in forecasting movement and character of the storm.

As the storm neared the 140th meridian, the Weather Bureau office in San Francisco transferred responsibility for issuance of advisories to the Weather Bureau in Honolulu. The Hawaiian military meteorological offices, responsible for slightly different areas than the Weather Bureau, had already begun issuing their warnings, and had named the storm Kanoa, a Hawaiian word meaning loosely "the free one."

As Kanoa approached the 145th meridian, it became apparent that there would be little or no chance for recurvature as the semipermanent Pacific High was strengthening to the north, and ridging farther westward (figs. 1, 2). This formed an effective block, such as is suggested by Simpson [3], at least in the lower layers. Aloft, a Low formed just to the northeast of the Islands, and was later reinforced by colder air from a trough